



UPDATE ON: Mesospheric/Upper Stratospheric Temperature and Related Datasets (MUSTARD): Producing a long-term record from limb sounding radiometers and occultation instruments

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Workshop of the SPARC Atmospheric Temperature Change Activity

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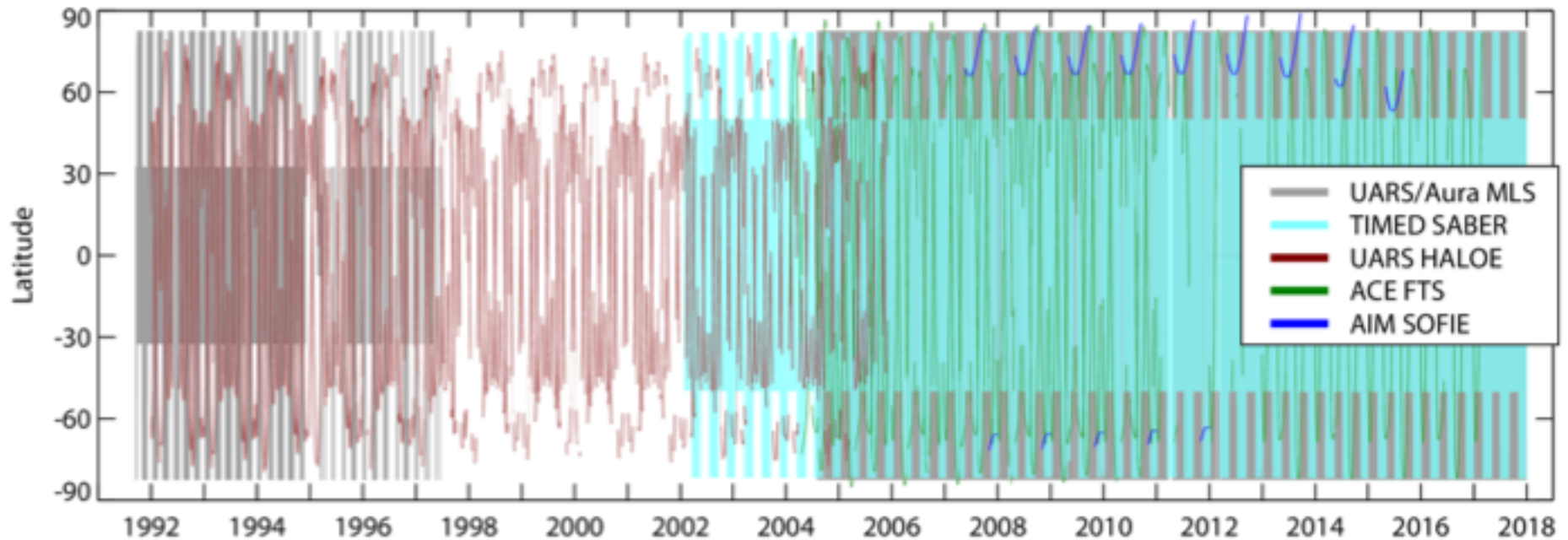
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Mesospheric and Upper Stratospheric Temperature and Related Datasets

- MUSTARD is a JPL-led, MEaSUREs-funded project to produce a long-term observational record of US/M temperature and GPH.
 - Three Limb Emission Radiometers:
 - [UARS MLS](#) (1992–1997), [Aura MLS](#) (2004–present) and [TIMED SABER](#) (2002–present)
 - provide near-global, daily, day & night, along-orbit coverage -->daily/monthly maps
 - good vertical resolution in the middle atmosphere compared to nadir sounders
 - Three Solar Occultation instruments:
 - [UARS HALOE](#) (1992–2005), [ACE-FTS](#) (2004–present), [AIM SOFIE](#) (2007–present)
 - provides excellent precision and vertical resolution
 - sparse latitudinal and temporal coverage is limited to one sunrise and sunset per orbit
 - US/M temperature data sets are generally high-quality and well-characterized
 - HALOE operational period overlaps that of all three emission radiometers, providing a potential transfer standard
 - Odin SMR, UARS ISAMS, COSMIC and LIDAR could provide correlative data.
 - SSU, SSMIS were not included (they lacked definitive temperature products)

Temporal and Latitudinal Coverage of Observations



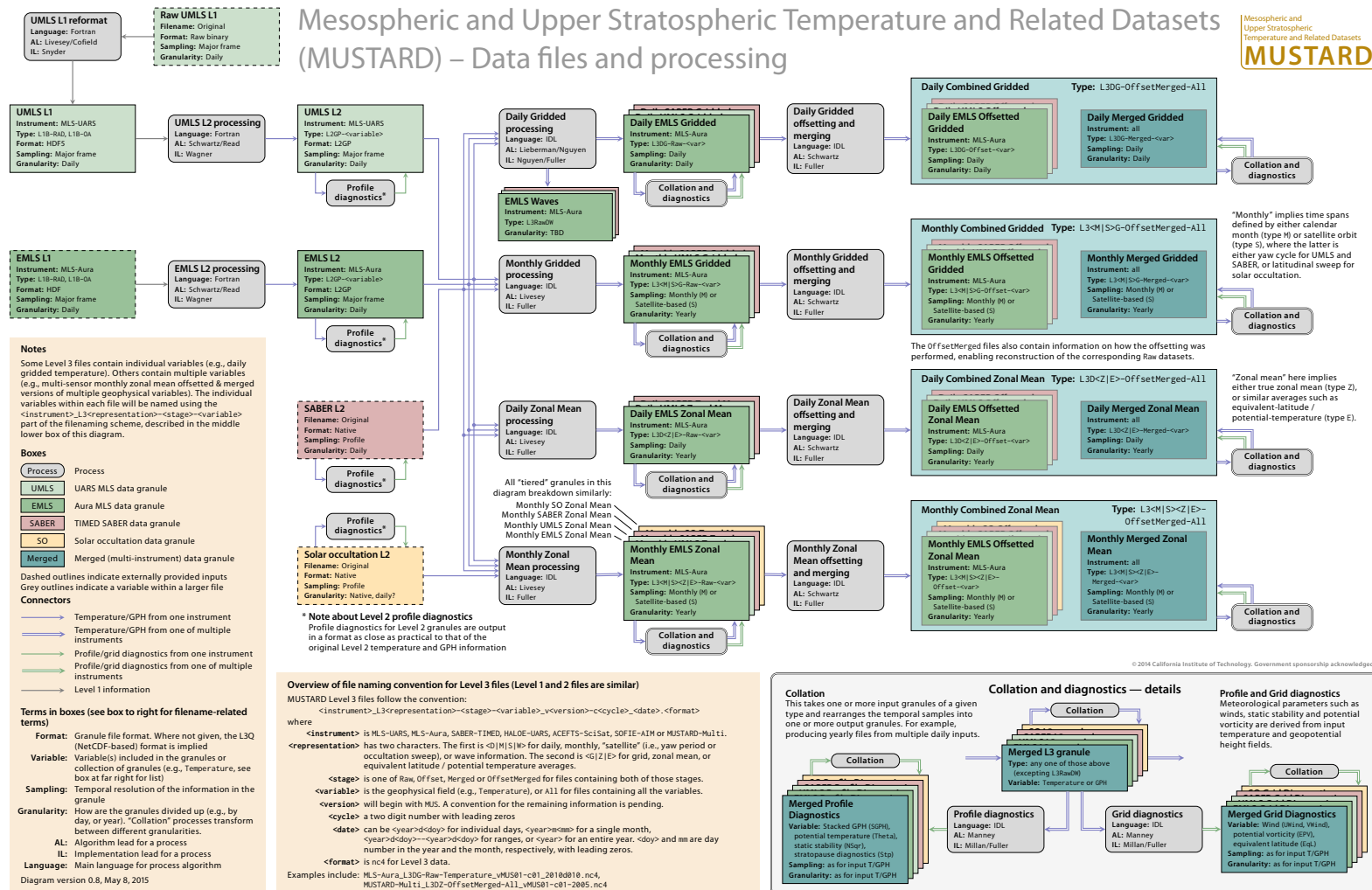
- Emission Radiometers: provide daily, near-global coverage
 - UARS, TIMED observe high latitudes in only one hemisphere at a time, yawing ~monthly
 - Aura is sun synchronous while UARS and TIMED observation times precess
- Solar occultation instruments:
 - HALOE and ACE-FTS sunrises and sunsets move through latitudes (~monthly)
 - AIM SOFIE observes only high latitudes.

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 - MLS Science Team members at JPL
- Gloria L. Manney (Co-I) Northwest Research Assoc./NMT, [Luis Millan](#)
 - Derived meteorological fields leads
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 - Spectral decomposition and synoptic mapping leads
- John Anderson, (Co-I) Hampton University
- Collaborators
 - James M. Russell (Hampton University) AIM and SABER PI
 - Kaley A. Walker, (University of Toronto) ACE-FTS deputy PI
 - I. Stuart McDermid, (JPL) Ground-based LIDAR correlative data
 - Karl Hoppel (Naval Research Laboratory)

- New UARS MLS and Aura MLS Level-2 temperature (profiles at measurement locations)
 - Definitive UARS MLS US/M temperature, properly accounting for Zeeman splitting of lines by the geomagnetic field, leveraging Aura MLS operational code
 - “Independent” Aura MLS US/M temperature using trendless, climatological a priori
- Produce monthly maps and daily and monthly zonal means from the three radiometer data sets and monthly zonal means from the three occultation data sets
- Use “Salby” zonal wave analysis of the radiometer data, accounting for longitude/time precession of zonal observations:
 - characterize diurnal-scale zonal variability (tides, multiday zonal waves)
 - reconstruct synoptic (00Z, 12Z) daily maps.
- Identify biases between instruments, using Fourier components to reconstruct radiometer observations at correlative observation times/locations and using HALOE observations (which overlap the three radiometers) as a transfer standard
- Produce bias-corrected “merged” versions of all six temperature records
- Produce derived fields including GPH, winds, PV, static stability, stratopause height.



Mesospheric and
Upper Stratospheric
Temperature and Related Datasets
MUSTARD



Current State of the project



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- Modified level-2 is complete for the Aura MLS record through March, 2018
 - In addition to GPH-StdProd and Temperature-StdProd, Swaths have been added for Merra-2 products sampled as MLS, Apriori and GPH-onRefGPHMerra2_56hPa
 - Initial comparisons with Aura MLS standard v04.2x processing suggest that trends between the two at recommended retrieval levels, if they exist, are less than 0.1K/decade.
 - Some differences arise from poor initial guesses of tangent-point pressure used in selecting radiances used in vMUS01.50
 - Some differences result from MUSTARD ozone retrieval not being constrained by ozone bands used in production v4
- Level-2 is nearly complete for UARS MLS (probably done by the end of this meeting)
- Level-3 preliminary “binning” algorithms have been run for EMLS, SABER and the occultation instruments and will be run for umls as soon as level-2 is complete and has undergone preliminary inspection

L3DZ:	Level 3 Daily Zonal (UMLS, SABER, EMLS)
L3MZ:	Level 3 Monthly Zonal (All)
L3MG:	Level 3 Monthly Gridded (EMLS)
L3SG:	Level 3 Satellite Period Gridded (SABER, UMLS on Satellite Yaw-cycle “months”)
L3SZ:	Level 3 Satellite Period Zonal (SABER, UMLS on Satellite Yaw-cycle “months”)

For comparison of overlaps of satellite instruments, emls is being run on SABER and UMLS months as well

- Preliminary Level-3 “Salby” algorithms were run on EMLS and a second iteration is currently running

L3DGM:	Level 3 Wave Coefficient (UMLS, SABER, EMLS,)
L3DGD:	Level 3 Daily Gridded Synoptic (00Z 12Z) Reconstruction

- Inspection is ongoing. We are just transitioning from mechanics of getting software producing data to more subtle validation and science. We hope to have useful products later in 2018.
- I am just starting to look at bias adjustments for harmonization of the overlapping data sets. Complete runs of level-3 will greatly facilitate this process.
 - I read with interest Robin Wing et al. 2018 AMTD, which compares EMLS and SABER with the OHP lidar.
 - I will be using an improved emls GPH product in the conversion from height to pressure (MUSTARD products are on pressure surfaces), but I don't believe that I am going to be able to justify (from an instrument science perspective) the >km scale height adjustment of emls that were shown to align EMLS and LIDAR stratopauses.
 - This will be an area of near-term work, and I will be looking at the implications of mls Averaging Kernels
 - Comparison of radiometer data (umls, saber, emls) with correlative data will be done with reconstruction at measurement locations, as possible. Salby coefficients used in reconstruction must be processed and validated.
 - Reconstruction becomes fraught late in umls mission, as scan stalls make data increasingly sparse. I am grappling with how to quantify the quality of the reconstruction.

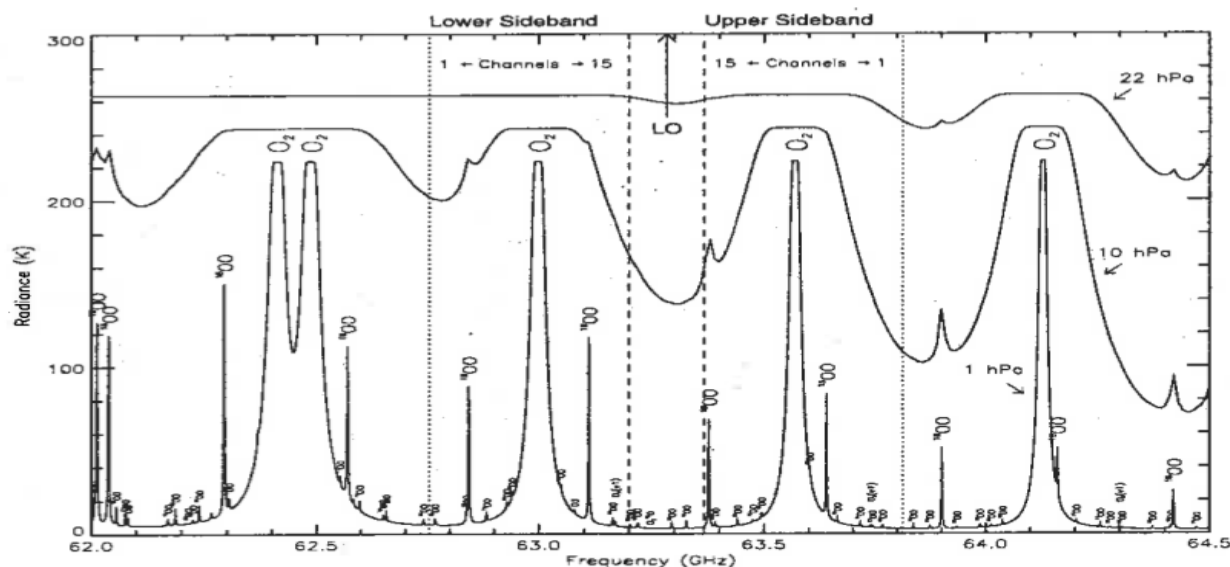
MUSTARD PROCESSING STATUS (as of June 26, 2018)



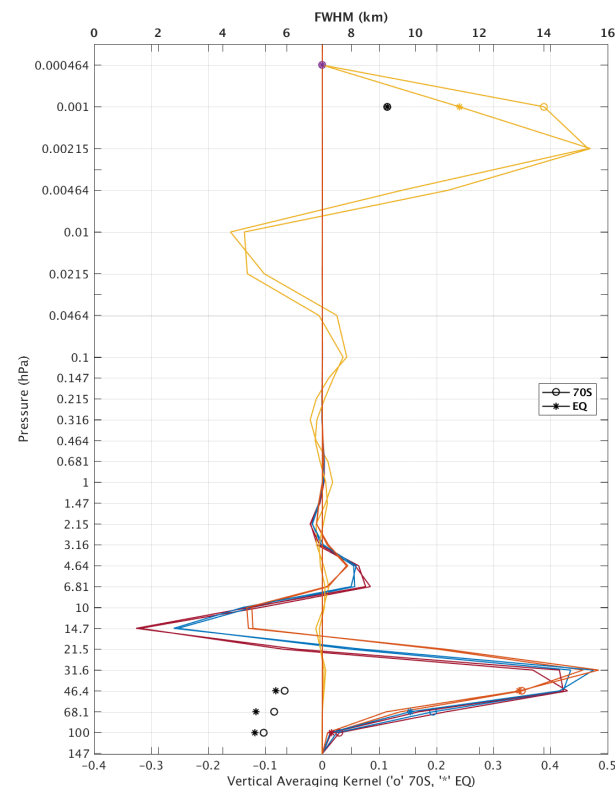
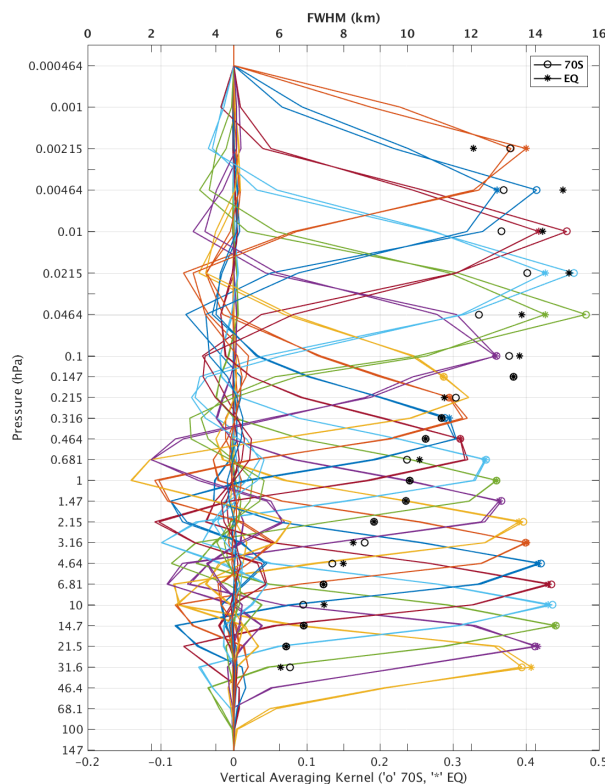
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	EMLS (2004 -2018)	UMLS (1991 – 2001)	SABER (2002-2018)	SOFIE (2007-2013)	ACE-FTS (2003-2017)	HALOE (1991-2004)	Multi- sensor
Level 1 (L1BOA, L1BRAD)	MLS V4.20 – V4.23	V1.4 9/18/1991- 2001	n/a	n/a	n/a	n/a	n/a
Level 2 (L2DGG, L2DGM, L2FWG)	vMUS01.50 8/2/2004- 3/31/2018	vMUS01.50 1991: 104/105 1992: 355/355 1993: 342/344 1994: 257/257 1995: 202/202 1996: 214/215 1997: 0/71	n/a	n/a	n/a	n/a	n/a
Level 3 yearly (L3DZ, L3MG, L3MZ)	V1.5 2005-2010, 2013-2017		V1.0 2002-2006, 2008-2015	n/a	n/a	n/a	
Level 3 Yearly (L3MZ)	n/a	n/a	n/a	V1.0 2011-2012	V1.0 2005	V1.0 1991- 2004	n/a
Level 3 Daily (L3DG, L3DG- Wave)	V1.5 1/1/2005 - 3/31/2018 (Except: Jan-Apr, Nov- Dec 2006 Mar-Apr 2011, Jan-Feb 2012)	n/a	n/a	n/a	n/a	n/a	n/a
Level 3 Salby Method (L3DG, L3DG- Wave)	n/a			n/a	n/a	n/a	
Level 3 Satellite Period (L3SG, L3SZ)	n/a			n/a	n/a	n/a	

- UARS MLS observes two O_2 lines near 63 GHz in the 50—70 GHz band of O_2 spin-rotational lines.
- Coupling with the geomagnetic field breaks these two lines into 198 components (the 118-GHz line used by Aura MLS has 3)
- Mesospheric radiances depend significantly upon field strength and orientation, even though Zeeman components are not resolved by the 2-MHz wide UARS center filterbank channels.
- A fraction of our current computational resources is sufficient to reprocess UARS MLS level 2 with the "Aura" algorithm, including line-by-line, polarized radiative transfer with derivatives.
- UARS views perpendicular to the satellite path, so no we can't do a 2D tomographic retrieval, but magnetic field gradients along the line of sight are modeled.
- UARS MLS 63 GHz FOV is $\sim 2\times$ broader than that for the Aura MLS 118 GHz observations

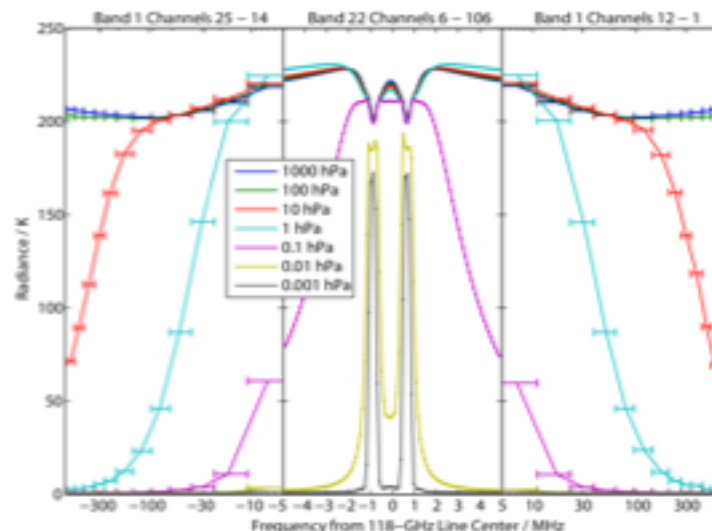


- The reprocessing of the UARS MLS to produce temperature and GPH level-2 products (along track geophysical quantities) is complete for 1991-1995. 1996-1997 will be complete in early July, 2018.
- 1995-1997 are increasingly sparse due to the malfunction of the instrument scanning mechanism.
- Averaging kernels are not routinely produced, but the averaging kernels are reasonably stable with variations of retrieved profile and geomagnetic field.
- UMLS AVKs for recommended retrieval levels at the Equator and 70S are shown in the left plot.
- Resolution (FWHM) varies from ~6km in the lower stratosphere to ~14km in the mesosphere, and is shown with black dots using the scale at the top of panels.
- The previous UARS (v5) retrieval did not account for geomagnetic effects and recommended levels were restricted to the stratosphere. .
- Above and below the recommended levels, AVKs do not peak sharply at the desired atmospheric level.



- Refinements to Aura MLS retrieval algorithms for MUSTARD reprocessing goals included:
 - ✧ Use of a trendless temperature *a priori* rather than GEOS-5 (done)
 - ✧ Better assumed O₂ mixing ratio (done)
 - ✧ Improved assumed geomagnetic model (attempted, made negligible improvement)
 - ✧ Extended forward-model 2D representation in the direction of the spacecraft to better account for saturated line centers
(Done. 8 profiles in representation basis on spacecraft side of tangent point led to less improvement than hoped)
 - ✧ Adjustment smoothing parameters (done)
 - ✧ Attempt to improve internal consistency of saturated and hydrostatic temperatures (radiances still subsetted like v04.2x)

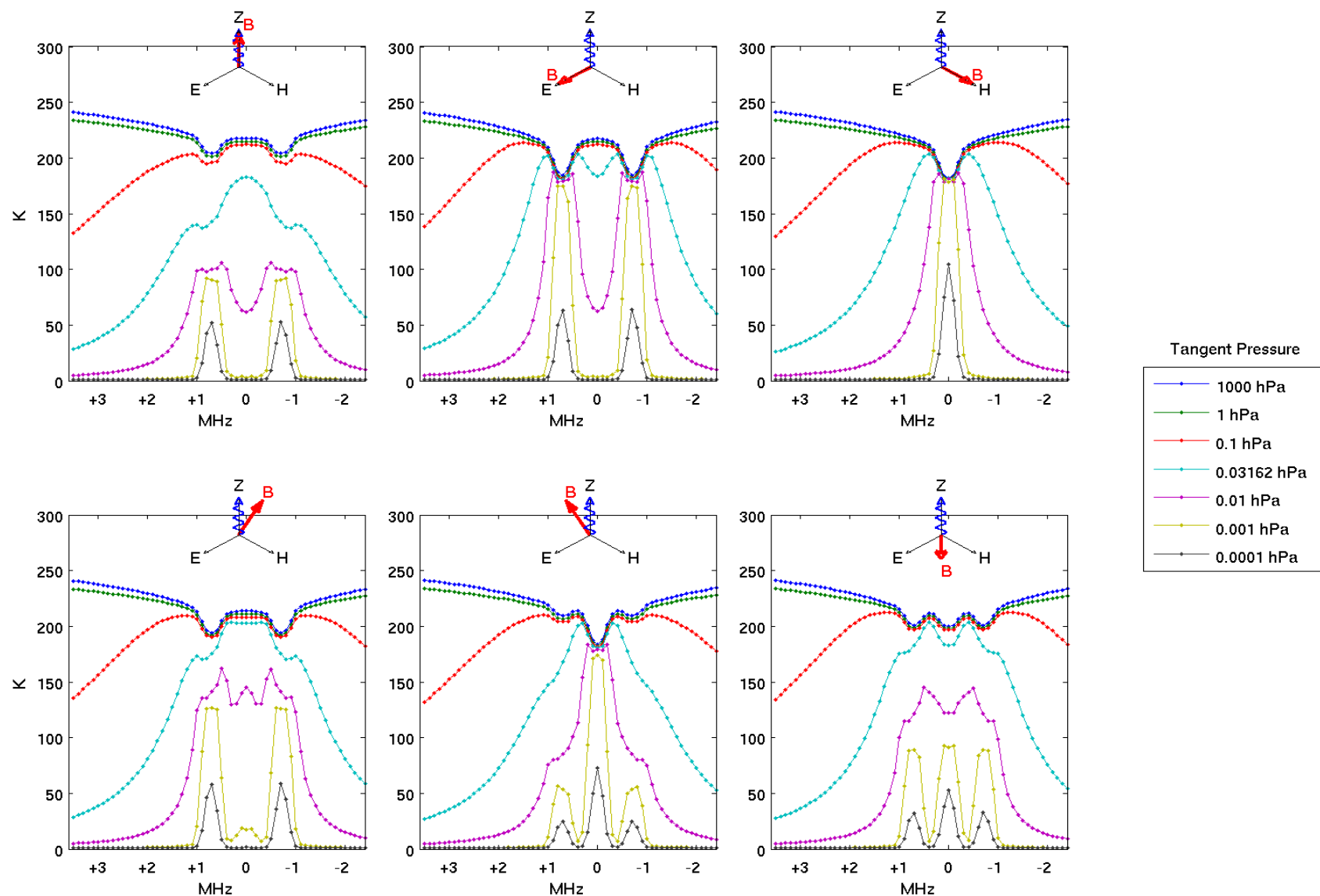
Typical high-latitude radiances showing two "sigma" Zeeman components for R1A orientation



Note extremely nonlinear frequency grid for B1 channels

Geomagnetic Field Orientation Dependence of Zeeman-Split O₂ Line Limb Radiances (118-GHz)

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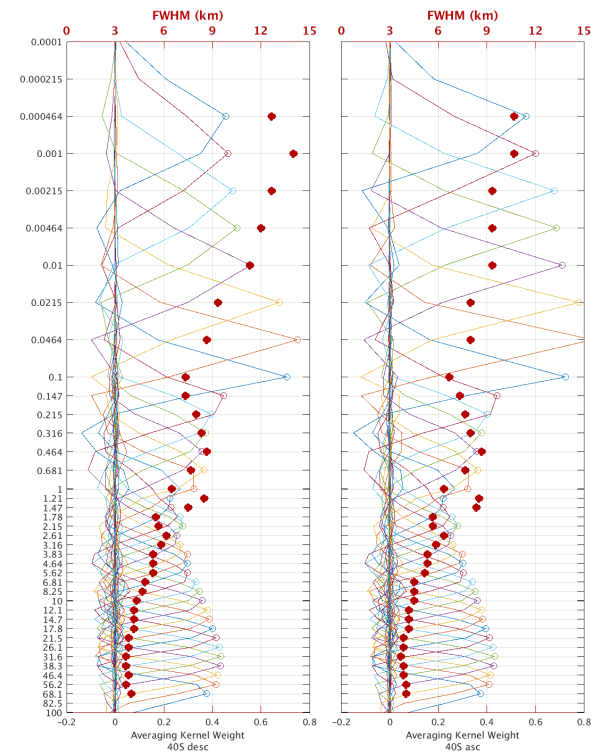
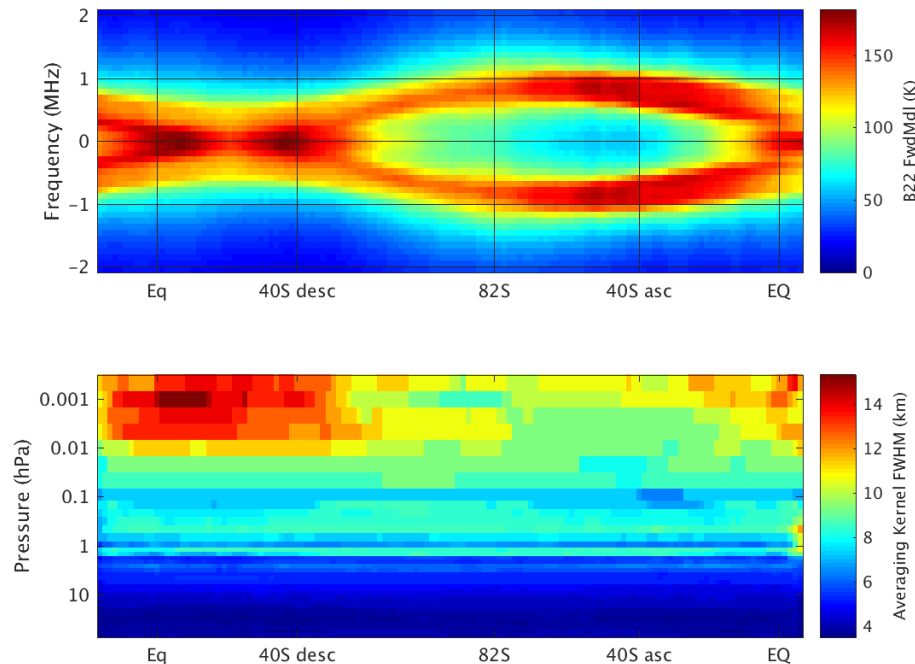


Aura MLS Band 22 Radiances and Averaging Kernels



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- Forward model radiances (upper left) show variability in Zeeman splitting around half orbit due to variability in viewing orientation relative to the geomagnetic field.
- The field is not a symmetric dipole and orientation changes at midlatitudes, ascending vs descending, leading to very different splitting
- AVK FWHM (lower left) can vary from 9—14 km in the mesopause region, even at the same latitude
- AVKs are shown for two passes through 40S in this half orbit chunk (lower right).

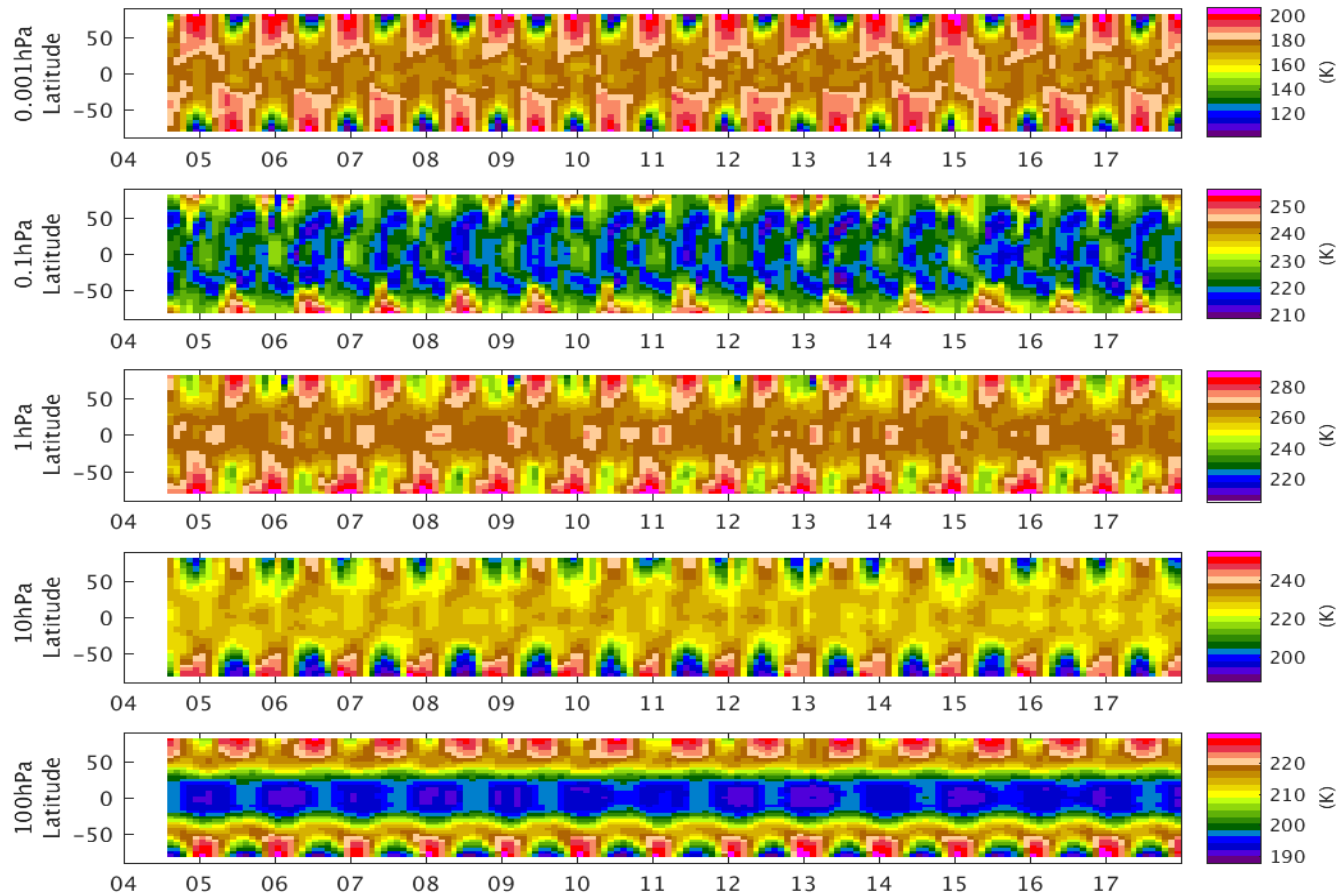


EMLS Calendar month zonal mean example

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MUSTARD EMLS vMUS01.50 Temperature



I have tons of stuff to inspect!